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Collective experimentation: a laboratory study

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Collective Experimentation: A Laboratory Study

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Abstract

We develop a simple model of collective experimentation and take it to the lab. In equilibrium, as in the recent work of Strulovici (2010), majority rule has a bias toward under experimentation, as good news for a minority of voters may lead a majority of voters to abandon a policy when each of them thinks it is likely that the policy will be passed by a future majority excluding them. We compare the behavior in the lab of groups under majority rule and under the optimal voting rule, which precludes voting in intermediate stages of the policy experiment. Surprisingly, simple majority performs better than the (theoretically) optimal voting rule. Majority rule seems to be more robust than other forms of voting when players make mistakes.

1 Introduction

Groups and societies often face decisions whose consequences for different individuals are uncertain and can only be learn over time. As an illustration, trade reforms, changes in immigration or environmental policies, big overhauls of the public health or the tax system, etc. often have consequences that are heterogenous and hard to forecast for different individuals. Policy innovation in those circumstances is akin to an experiment conducted by the society which may result in the new policies being entrenched or abandon as new evidence mounts up. Such experiments open a new dimension to the collective choice problem, since majority preferences in favor or against the new policies may change over time. In order for the society to make decisions, it is necessary to specify not only a voting rule but also how this rule is going to change over time. In this paper, we develop a simple model of the dynamic collective experimentation problem. We use lab evidence to explore the efficiency

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implications of different dynamic voting rules from a utilitarian perspective, and to compare game theoretic predictions with the behavior of subjects in the lab.

In the model, group members must decide whether to adopt or not a policy. It is unclear ex ante who will benefit and who will lose from the policy. Individuals may learn that they will win from the reform in two subsequent stages, after which they have to decide whether to stick to the policy for good or abandon it. As in Strulovici's (2010) influential contribution, the policy may be derailed in an intermediate stage if a minority learns that they will be winners, as voters in the remainder may anticipate the policy could be adopted in the final stage even if they emerge individually as losers. In the context of the model, the optimal voting rule specifies unanimity at intermediate stages and simple majority in the final stage. The lab implementation reveals, surprisingly, that adopting simple majority throughout yields more efficient outcomes than the (game theoretic) optimal voting rule. The reason is that simple majority is more robust to individual voters making mistakes in a dynamic sense: the majority at the intermediate stage may derail policies that could be adopted later on for good by a different majority by mistake. We also investigate whether the bias toward overoptimism may be due to persistent versus temporary overoptimism, and present evidence consistent with the latter.

The efficiency advantages of unanimity versus simple majority is, of course, a classical theme in political economy, at least since the publication of the *Calculus of Consent* (Buchanan and Tullock, 1962). To the traditional trade-off, predicated in a static setting, our work adds a dynamic dimension. Evidence from the lab indicates that repeated majority voting is self-correcting in a way that is not captured by equilibrium analysis. In our setting, majority voting at an intermediate stage allows to overcome an overoptimism bias. Subjects' voting behavior is consistent with them overestimating their probability of success after failing to receive high signals.

There is by now a growing theoretical literature on collective experimentation problems. Fernandez and Rodrik (1991) provide the seminal contribution, showing that a policy may have minority support ex ante even if it will have majority support ex post for sure if individual voters are afraid of ending up in the losing minority. The above-mentioned article by Strolovici models collective experimentation as a continuous time game with a continuum of voters, identifies the deviations from efficiency implied by adopting majority voting at every moment and derives the (time contingent) optimal voting rule. Our model recovers the strategic elements of Strulovici's (2010) model in a discrete time setting with few voters in a way that can be taken to the lab. This allows to check whether the strategic incentives identified by the literature operate in a controlled setting, and explore deviations from equilibrium predictions and their consequences.

Other recent theoretical work on collective experimentation has focused on collective search by committees, as in the work of Albrech et al. (2010) and Moldovanu and Shi (2013), on optimal voting rules for two period models, as in the work of Messner and Polborn (2012), on incentives to over-experiment for preemptive reasons when the policymaker may not remain in power, as in Callander and Hummel (2014), on dynamic sequential acquisition by committees, as in Chan et al. (2015), and on extending Strolovici's model to consider bad signals, as in Khromenkova (2017). In spite of the growing interest and relevance of this line of work, we are not aware of other lab research on dynamic collective experimentation.

The remainder of this paper organized as follows. Section 2 presents the simple collective experimentation model we use and provides theoretical predictions. Section 3 provides details about the experimental design. Section 4 presents results obtained from the experiment. Section 5 gathers final remarks. All omitted proofs are collected in the Appendix.

2 Theoretical framework

We consider a simple three period voting game with three players in which players choose between a safe and a risky project. Players can be of two types: high or low, depending on whether the player receives a high (h) or a low (l) payoff if the risky project is implemented. All players receive a payoff of s if the safe project is implemented, independently of type, where $h > s > l$.

In the first period, players vote on whether to start experimenting or not. If they start experimenting, each player receives a public signal. The signal can be *high* or *uncertain*. If the player receives the high signal, then the player's payoff from implementing the risky project is h. If the signal is uncertain, the player does not know which payoff the player would receive in case of implementing the risky project. If the player is of high type, then there is a probability $q \in (0, 1)$ that the player will receive the high signal, while if the player is of low type, there is a probability of zero that the player will receive a high signal.

In the second period, after observing the public signals received by all players, players vote on whether to continue experimenting. If they continue, they receive signals again. For notational simplicity, since their type has been already disclosed, we assume that players who received high signals in period 1 receive them again in period 2. For the reminder of players, as in the previous period, then there is a probability $q \in (0, 1)$ that the player will receive the high signal, while if the player is of low type, there is a probability of zero that the player will receive a high signal. We denote by $w_t \in \{0, 1, 2, 3\}$ the total number of "High" signals received in period $t \in \{1, 2\}$, with $w_2 \geq w_1 \geq 0$.

Finally, in the third period, players vote on whether to implement the risky project or the safe project. If the risky project is implemented, all voters' types are disclosed; in either case, all payoffs are realized.

Denote by p_0 the initial probability that the player is of a high type. Using Bayes' Law, the probability that a player is of high type after receiving an uncertain signal in period 1 is

$$p_1 = \frac{p_0(1-q)}{1-p_0 q},$$

and the probability that a player is of high type after receiving uncertain signals in periods 1 and 2 is

$$p_2 = \frac{p_1(1-q)}{1-p_1 q} = \frac{p_0(1-q)^2}{1-2p_0 q + p_0 q^2}.$$

We denote by

$$r = p_2 h + (1-p_2)l$$

the expected payoff from the risky project for a player that received uncertain signals in periods 1 and 2. We assume $r < s$, so that a player that does not receive high signals would prefer to adopt the safe project.

Note that a utilitarian social planner would experiment in periods 1 and 2, and would adopt the project in the third period if $w_2 h + (1-w_2)r > 3s$, and only if $w_2 h + (1-w_2)r \geq 3s$.

We investigate the behavior of agents in the model under majority voting. We also describe an optimal voting rule, i.e. a voting rule that implements the utilitarian social planner's choices. Our solution concept is Perfect Bayesian Equilibrium in undominated strategies. As customary in voting games, we eliminate weakly dominated strategies to avoid trivial equilibria in which no player is decisive. For notational simplicity, we assume that players vote to continue experimenting when indifferent.

2.1 Majority voting and under experimentation

In this section, we provide conditions under which, in equilibrium, majority voting deviates from the utilitarian social planner's choices by stopping the policy after a minority gets good news in period 1, but otherwise coincides with the social planner choices (see Figure 1). Parameter values satisfying these restrictions allow us to test whether majority voting leads to under experimentation as in Strulovici (2010).

We proceed by backward induction, from the last stage to the first. Since by assumption $h > s > r$, in the third period only players who have obtained a high signal vote to implement the policy, so the policy is implemented if $w_2 \geq 2$. The condition in Lemma 1 below implies that utilitarian social planner adopt the same decision than majority voting:

Lemma 1. *The utilitarian social planner and majority voting outcomes coincide in the third period if and only if*

$$\frac{1}{2} < \frac{h-s}{s-r} < 2.$$

In the second period, if $w_1 \geq 2$, then the policy is continued. If $w_1 = 1$, the two players who have not received a high signal will vote to terminate the policy if each of them perceives that there is a high enough probability that the other one will be eventually a winner and they will be the only losers:

Lemma 2. *If $w_1 = 1$, voters will abandon the policy in the second period if and only if*

$$\frac{h-s}{s-r} < 1 - p_1 q.$$

Note that, along the lines of Fernandez and Rodrik (1991), the policy is stopped in the second period even if it is likely to be supported by a majority in the third and final period.

Also in the second period, if $w_1 = 0$, all players will vote to continue the policy as long as there is a high enough probability of being winners in the end:

Lemma 3. *If $w_1 = 0$, voters will continue the policy in the second period if and only if*

$$\frac{h-s}{s-r} \geq \frac{1-p_1 q}{2-p_1 q}.$$

As in Strulovici (2010), the threshold for the policy to pass after $w_1 = 1$ is more demanding than the threshold for the policy to pass after $w_1 = 0$. That is, continuation of the policy experiment is not necessarily monotonic in the number of supportive signals obtained in an intermediate stage.

Finally, turning to the first period, all players support starting experimentation if the expected payoff is larger than or equal to the payoff of the safe project:

Lemma 4. *If*

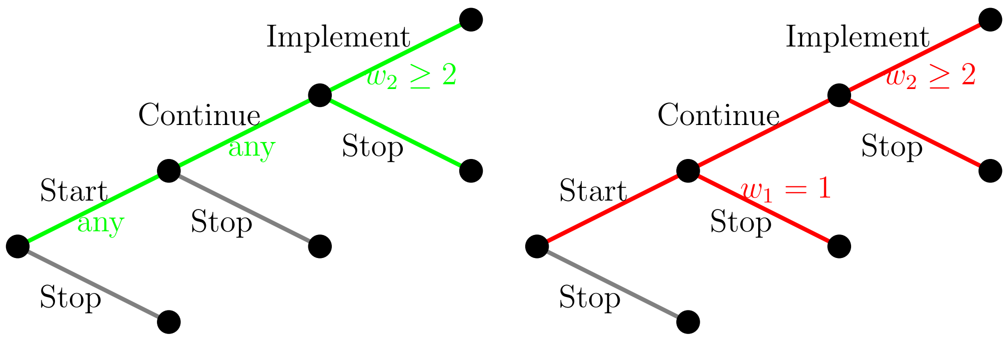
$$\frac{1-p_1 q}{2-p_1 q} \leq \frac{h-s}{s-r} < 1 - p_1 q,$$

voters will start experimenting with the policy in the first period.

Intuitively, the condition for players to experiment with the policy after getting uncertain signals, laid out in Lemma 3, is more stringent than the condition for players to be willing to experiment with the policy before getting signals.

2.2 Optimal voting rule

In this section, we show that a voting rule that requires simple majority to start the project in the first period and to adopt if for good in the third period, but specifies no voting in the second period (or requires unanimity to abandon the policy in the second period) implements the utilitarian social planner outcomes, as long as the conditions of Lemmas 1, 2 and 3 are



(a) Social Planner (b) Majority Voting

Figure 1: Decision Trees

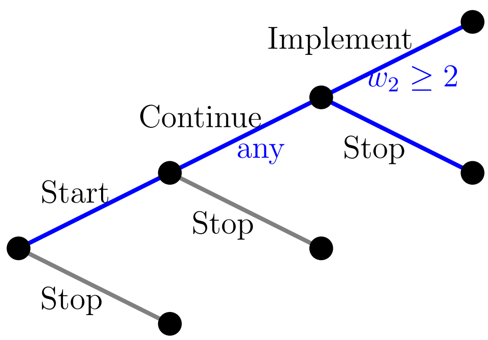


Figure 2: Collective Decision Tree for Time-Varying Quorum Rule Mechanism

satisfied. Note that the upper bound for $(h-s)/(r-s)$ in Lemma 2 is more demanding than the upper bound in Lemma 1, but the lower bound in Lemma 1 is more demanding than the lower bound in Lemma 3.

Figure 2 illustrates the collective decision tree for the putative optimal voting rule. Intuitively, this rule precludes players to stop the policy if only one high signal was received in the first period.

Lemma 5. *Suppose*

$$\frac{1}{2} \leq \frac{h-s}{s-r} < 1 - p_1 q.$$

Then, the voting rule that requires simple majority to start the project in the first period and to adopt if for good in the third period, but specifies no voting in the second period, implements the utilitarian social planner outcomes.

3 Experimental design

We conduct a lab experiment based on the theoretical model with the following parameter values (see Table 1). Parameters were chosen in order to satisfy the conditions stated in

Lemmas 1, 2 and 3. Therefore, equilibrium behavior predicts that simple majority would be suboptimal, while the optimal voting rule delivers outcomes that coincide with the utilitarian planner choices.

Parameter	Value
Probability of being high type p_0	1/2
Probability that signal reveals the type q	1/2
High payoff h	500
Low payoff l	50
Safe payoff s	350
Exchange rate	20 tokens per US dollar

Table 1: Parameters specification

The experimental design consists of two treatments. In the first treatment, subjects make decisions under simple majority and in the second one under the optimal voting rule. We refer to them as *majority treatment* and *optimal treatment*. The game was played 15 rounds with random reshuffling of the groups, to ensure that the were no repetitions with the same group composition. The experiment was coded and conducted using oTree (Chen et al., 2016). Experimental instructions can be found in the appendix. We conducted the experiment with 60 undergraduate students from George Mason University. There were 36 subjects in the majority treatment and 24 in in the optimal treatment. Subjects' earnings varied between \$10 and \$40.

4 Experimental results

We start by looking at group level results to test theoretical predictions and compare the performance of the two voting rules. Then we move on to analyzing individual behavior to explore possible biases which caused the observed group level behavior. Finally, we present results from the structural estimates of the Quantal Response Equilibrium model (introduced by McKelvey and Palfrey, 1995, 1998).

4.1 Group level analysis

Figure 3 summarizes the results. Red numbers correspond to the frequencies of action in the majority treatment and blue numbers correspond to the frequencies in the optimal treatment. Green lines correspond to optimal (utilitarian planner) choices. A first observation is that subjects (in both treatments) start the project with very high probability which is in line with theoretical predictions.

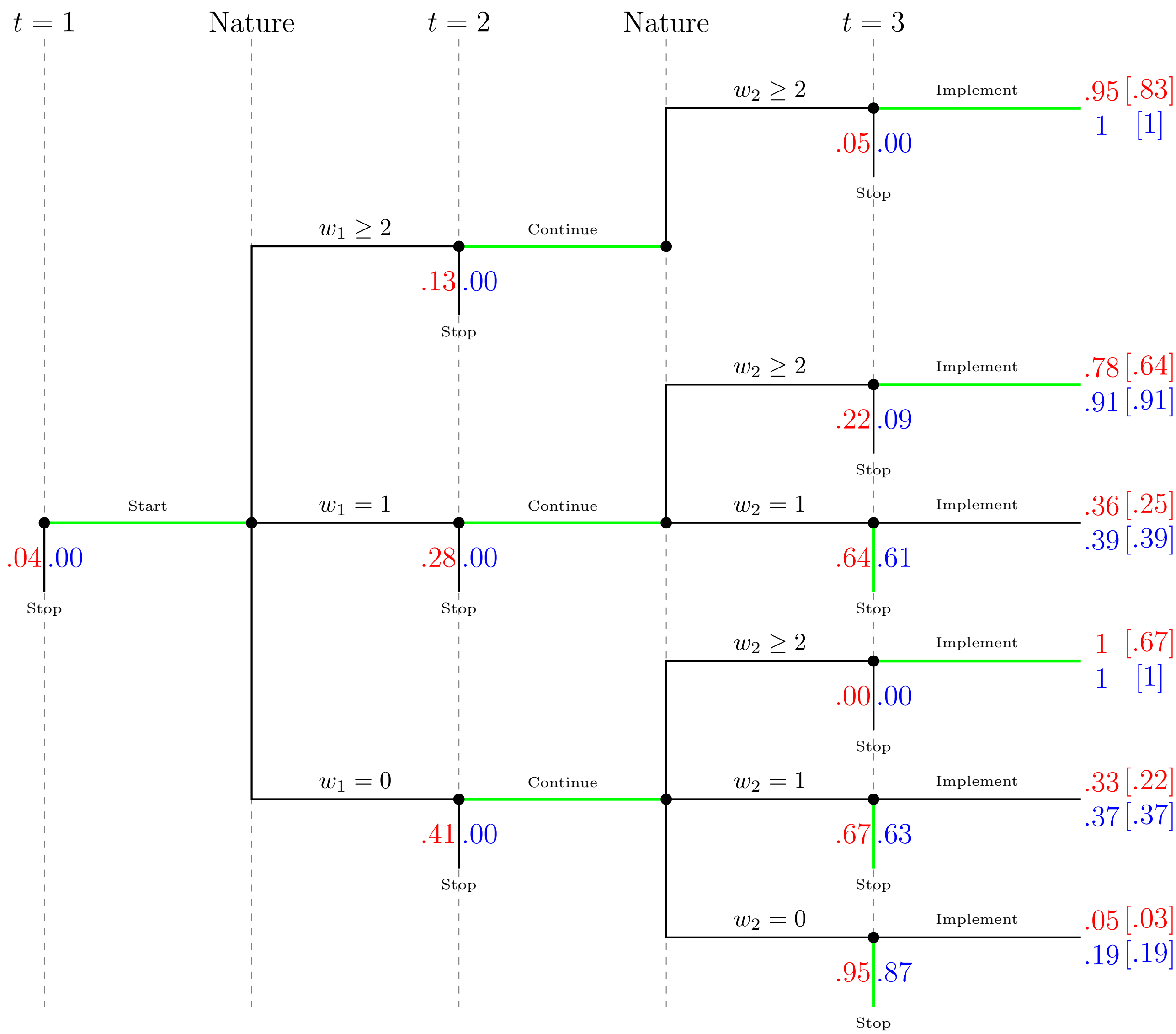


Figure 3: Probabilities of abandoning and implementing the policy on the collective decision tree. Red and Blue numbers correspond, respectively, to the frequencies obtained in the majority treatment and in the optimal treatment. Green lines correspond to the socially optimal decisions at every node. Stopping frequencies and frequencies of policy implementations displayed are conditional on the probability of reaching the node. In square brackets we show probabilities of implementing the policy conditional only on the history of signals received.

(w_1, w_2)	Probability	Observed frequency		Equilibrium earnings		Observed earnings	
		Majority	Optimal	Mayority	Optimal	Mayority	Optimal
(0,0)	.244	.220	.300	0	0	-16.15	-122.5
(0,1)	.147	.100	.160	0	0	-60	-99.47
(0,2)	.029	.011	.025	90	90	90	90
(0,3)	.002	.006	.000	450	450	0	$\emptyset$
(1,1)	.293	.310	.190	0	0	-67.5	105.65
(1,2)	.117	.100	.180	0	90	63	81.43
(1,3)	.012	.011	.000	0	450	0	$\emptyset$
(2,2)	.117	.156	.130	90	90	77.14	90
(2,3)	.030	.060	.008	450	450	368.18	450
(3,3)	.016	.017	.008	450	450	300	450
Expected				34.74	50.67	2.31	-32.10

Table 2: Normalized expected revenue

Recall that the theoretical deviation of majority voting from optimal utilitarian behavior happens at $t = 2$ if one high signal is received. Equilibrium predicts that the policy will be abandoned in this case, while optimality requires to continue the policy. In the experiment, policy is abandoned with a frequency of 26%, which is significantly lower than equilibrium would predict (with $p < .001$). At the same time, the observed frequency of stopping is significantly higher than what would be optimal. Moreover, there is also significant under-experimentation in the case of no high signals received. If two or more high signals were received, the policy was terminated with a frequency of 13% . This under-experimentation is not robustly significant ($p = .02$ according t-test and $p = .06$ for Wilcoxon test).

Numbers in square brackets at the final leafs of the game tree in Figure 3 show the frequency of policy implementation for the different possible trajectories of high signals received. We can see that the optimal voting rule implements significantly ($p < .01$) more frequently the policy when it is efficient to do so ($w_2 \geq 2$) is implemented. However, we also see that the optimal voting rule implements significantly ($p < .05$) more frequently the policy when it is *inefficient* to do so ($w_2 < 2$). Moreover, neither of the two treatment effects is eliminated with learning.

Note that significant over-experimentation is not caused by subjects using different strategies in different treatments at $t = 3$. Numbers below the leaves, corresponding to stopping the policy in $t = 3$, show the frequency of abandoning the policy in the last period conditioning on continuing the project at $t = 2$. There are not significant differences over treatments in these frequencies. Subjects use similar strategies in the last period (at least on the group level); the forced continuation of the policy caused by the (theoretically) optimal voting rule leads to an over-implementation of policy.

Table 2 presents revenue outcomes for the two treatments. The first column lists all possible signal histories for a group. The second one shows the theoretical probabilities with which the history appears. The third and fourth columns show the observed frequencies for every history by treatment. Note that there are deviations from theoretical probabilities in both treatments, and there are differences in frequencies between treatments. For comparison purposes, we use theoretical probabilities instead of observed frequencies to compute expected earnings for every treatment. The fifth and sixth columns show earning outcomes for the group for every history derived from theoretical equilibrium behavior. The last two columns show the averaged observed earning outcomes for every history. (The symbol $\emptyset$ denotes histories for which there is no observations and correspond to the zero observed frequency events.). Revenue data is normalized by subtracting $1050 = 350 \times 3$ (revenue for the group from the safe project). Hence, numbers in the last two columns indicate net gains or loses from implementing the policy instead of the safe payoff.

Expected observed revenue is higher in the majority rule treatment. This is caused by significant over-experimentation in the optimal voting rule treatment. We conduct a two-step bootstrapping procedure (see Appendix B for details) that confirms the statistical significance of the differences in expected net earnings presented in Table 2. Expected group revenue under the optimal voting rule is in fact negative–the group is doing worse than always staying with the safe payoff. This is a consequence of both over implementation and the fact that with our parameter specification most probability weight lies in the domain where behavior under the optimal voting rule leads to inefficient outcomes.

4.2 Individual level analysis

In the section we turn to the analysis of observed individual behavior. In particular, we investigate possible behavioral biases causing observed group level results.

Recall that the equilibrium action in both treatments in the first period is to vote to start the policy, and in the third period it is to vote to implement the policy for good in the third period if a player has obtained a high signal, and against implementing the policy if the player has not obtained a high signal. In the second period, in the majority treatment, under our parameter specification, the equilibrium action is to vote to continue the policy if a player has obtained a high signal or if no one else has obtained a high signal, and to vote to abandon the policy otherwise.

Figure 4 shows the probability of playing equilibrium actions. The first (blue) and the second (red) bars show, respectively, the probability of playing an equilibrium action in the optimal rule and in the majority rule treatments, aggregating over the first and third period in the optimal voting rule treatment, and over all three periods in the majority treatment. The third and fourth bars show the probability of playing an equilibrium action in the second an third periods in the majority treatment.

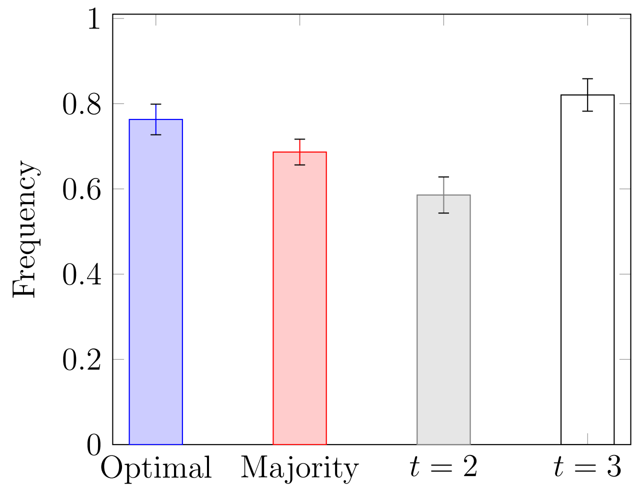
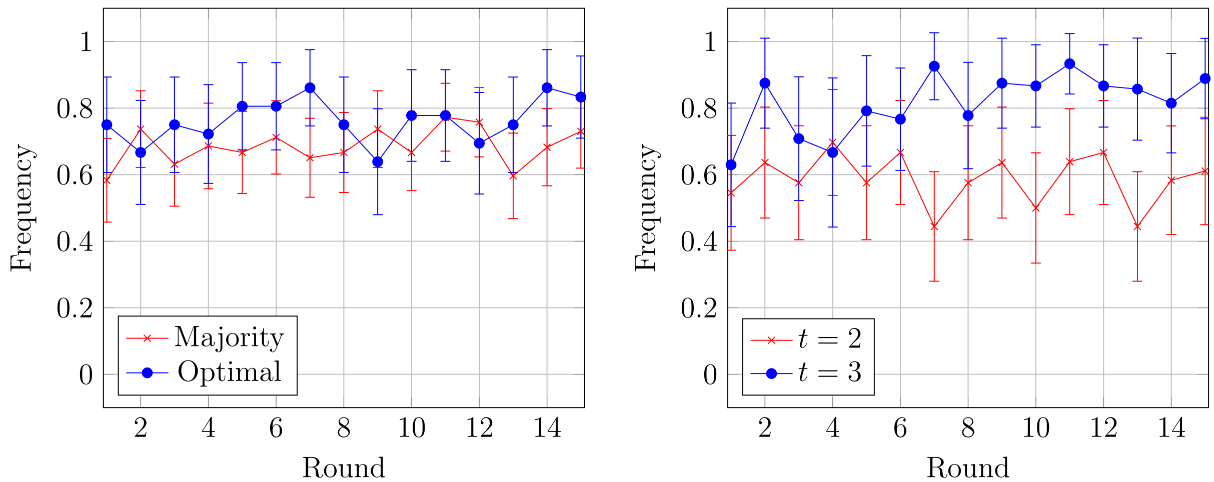


Figure 4: Frequency of playing equilibrium actions

The probability of playing equilibrium actions in the majority treatment is significantly lower than in the optimal treatment; as illustrated by Figure 4, this is due to the behavior of players in the second period. This behavior is not necessarily bad in terms of expected earnings. The reason is that equilibrium actions are (unique) undominated best responses in the third period, but they are not necessarily undominated best responses in the first and second period taking into account the *actual* behavior of players in subsequent periods. For instance, in the optimal voting treatment, given (negative) expected earnings, the undominated best response action in the first period would be to vote *against* experimenting with the policy. In the majority treatment, the undominated best response coincides with the equilibrium action in the first and third period, but does not coincide with the equilibrium action in the second period. In particular, given the observed frequencies in Figure 3, the best response action in the second period is to vote to abandon the project if $w_1 = 0$. In the majority treatment, deviations from equilibrium behavior in the second period help to counter deviations from best response behavior in the final period.

We investigate now whether subjects learn to play equilibrium strategies. Figure 5 shows the probability of playing equilibrium actions by round. Figure 5(a) presents the results for the two treatments. The probability of playing equilibrium actions in the optimal treatment is higher than in the majority treatment in most periods, though there is no single period in which the difference is significant. Figure 5(b) presents the results for the majority treatment decomposed by period. Comparing the behavior in the second and third periods we observe that overall the probability of playing equilibrium actions is higher at $t = 3$. Moreover, there is a significant increase in the probability of equilibrium actions in the third period under majority treatment ($p < .05$), but no significant increase in the second period. Since equilibrium actions are unique undominated best responses in the third period, there is evidence



(a) By treatment

(b) By period

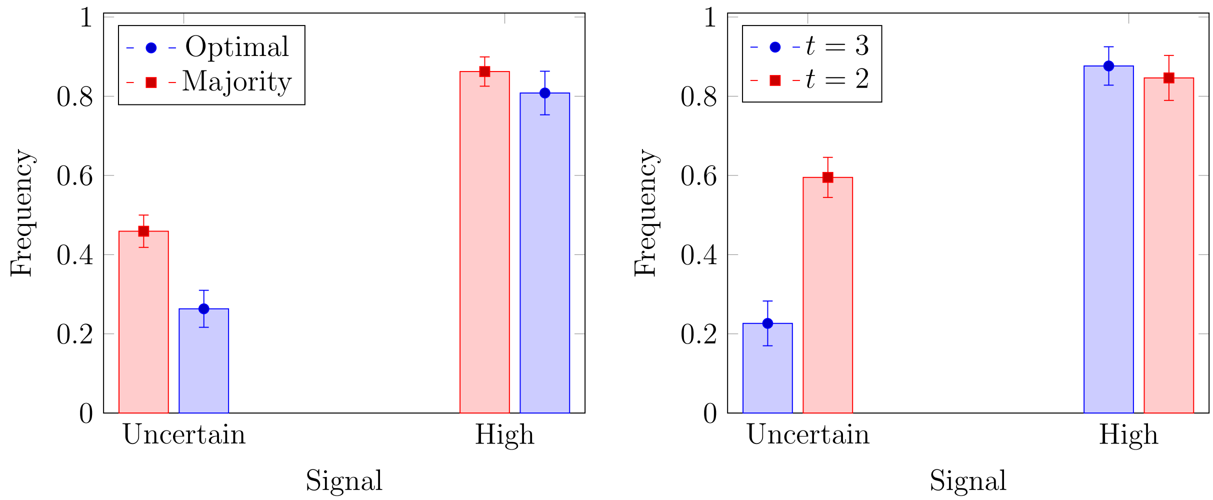
Figure 5: Frequency of playing equilibrium actions over time

of learning. The situation in the second period is more involved; if learning equilibrium actions in the third period were closer to completely successful, it would make sense to play equilibrium actions in the third period.

Figure 6(a) shows the frequency of voting for the policy conditional on the signal received for both treatments. Note that voting for the policy after a high signal is the unique undominated best response. There is no difference in voting for the policy in this case. Note also that voting for the policy after uncertain signals in the third period reduces the expected earnings of the player; it can be attributed to overoptimistic expectations regarding the revenue of the project for the player. For the optimal treatment, in particular, the frequency of voting for the policy (around 25%) is evidence in favor of a bias for overoptimism. For the majority treatment the situation is more involved; voting for the project in the third period is evidence in support of overoptimism, but voting for the project in the second period may or may not be a best response.

We investigate now whether overoptimistic behavior is persistent feature along the repetitions of the game. Figure 7 shows the frequency of voting for the policy after receiving an uncertain signal by round. Figure 7(a) shows the frequency for different treatments. This frequency declines over time for the optimal treatment, which is consistent with learning best responses (marginally significant at $p = .07$). It remains relatively high for the majority treatment, where it may reflect the fact that voting for the policy in the second period after an uncertain signal may be a best response (and in fact it is the equilibrium action if no one else obtains high signals).

Figure 7(b) shows the frequency of voting for the policy after an uncertain signal for $t = 2$ and $t = 3$ in the majority treatment over different rounds. The frequency is systematically



(a) By treatment

(b) By period

Figure 6: Frequency of voting for the project given the signal received

higher for the second period. This frequency declines over time for the third period, which again is consistent with learning best responses (marginally significant at $p = .08$.)

Next we investigate in the majority treatment whether players who receive uncertain signals in both periods vote for the policy in both periods as well. This may be evidence that these players are in fact overoptimistic.

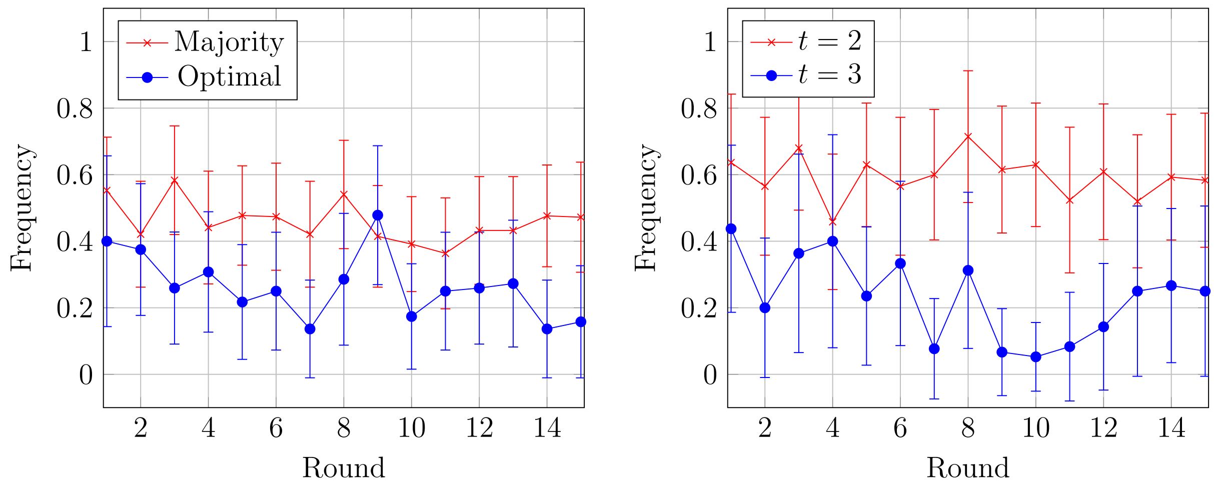
	All	Males	Females
$t = 2$ and $t = 3$	.1722	.1369	.2347
Only $t = 3$	.2125	.1738	.2808
Only $t = 2$	.5549	.6155	.4476

Table 3: Average frequency of voting for the policy when receiving uncertain signals in both periods

Table 3 presents the average frequencies for all sample and split by gender. A first observation is that there are no (statistically significant) gender differences in behavior patterns, against the common occurrence of gender differences in overoptimistic behavior. A second observation is that many players vote for the policy after two bad signals but not after one signal, so that overoptimism as a *persistent* trait cannot explain all the behavioral patterns.

4.3 A structural model

We estimate a simple Quantal Response Equilibrium model with behavioral types, similar to Elbittar et al. (forthcoming). The model has two parameters (Q, p) Q is a quantal response parameter while p is a type parameter. With probability $1 - Q$, each player uniformly



(a) By treatment

(b) By period

Figure 7: Frequency of voting for the project if uncertain signal is received over time

randomly choses one of two actions (voting for or against the policy). With probability p, a player who is not choosing randomly votes for the project no matter what. We interpret p as the probability of being (temporarily) overoptimistic.

Figure 8 illustrates the structural model. The probability that player i in period t votes for the policy ($v_t^i = 1$) is

$$P(v_t^i = 1 | s_t^i, w_t, p, Q) = Q((1-p)\hat{v}_t^i(s_t^i, w_t, p, Q) + p) + \frac{1-Q}{2},$$

where s_t^i is the player's signal, w_t is the number of high signals received in the period, p, Q are the QRE parameters, and $\hat{v}_t^i(s_t^i, w_t, p, Q)$ is the undominated best-response given the player's signal, taking the value of one if it is a best-response to vote for the project and zero otherwise. Best-response depends on the model parameters, since QRE assumes that each player not only deviates from best-response behavior with some probability, but also takes into account that other subjects do so while deciding what is the best-response. The probability that player i in period t votes against the policy ($v_t^i = 0$) is, in turn,

$$P(v_t^i = 0 | s_t^i, w_t, p, Q) = Q(1-p)(1 - \hat{v}_t^i(s_t^i, w_t, p, Q)) + \frac{1-Q}{2}.$$

Denote by n_t^v for $v \in \{0, 1\}$ and $t \in \{1, 2, 3\}$ the number of subjects who took decision v in period t. We can derive the following likelihood function for the majority treatment:

$$L(Q, p, n) = \prod_{t \in \{1,2,3\}} \left\{ \left(Q((1-p)\hat{v}_t^i + p) + \frac{1-Q}{2} \right)^{n_t^1} \left(Q(1-p)(1 - \hat{v}_t^i) + \frac{1-Q}{2} \right)^{n_t^0} \right\}.$$

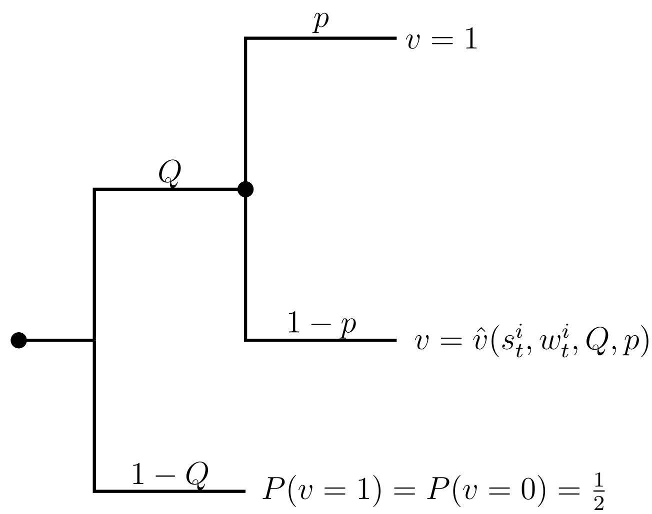


Figure 8: Structural model

For the optimal treatment we do not consider $t = 2$, since there is no decision made, so we take $n_2^v = 0$ for $v \in \{0, 1\}$.

	Q	p
Majority treatment	.76	.35
Majority treatment without $t = 2$	.77	.14
Optimal treatment	.87	.11
Pooled data	.78	.07

Table 4: Estimated parameters

Table 4 presents the results obtained from estimating the model based on majority treatment, optimal treatment and pooled data (including both majority and optimal treatments). Given the estimated parameters, best response in the second period is similar to best response in the third period: a player should vote based on the player's own signal, voting in favor of the policy after a high signal and against the policy otherwise. Note that for all estimated parameters the best response is to start a project in the first period. The bias in favor of accepting the policy, beyond uniform random deviations, is small and comparable in all cases, except for majority treatment when including $t = 2$. In that case, though, best-response behavior actually conflicts with Perfect Bayesian Equilibrium behavior, so the apparent overoptimistic bias may reflect strategic uncertainty.

Table 5 presents the probability of abandoning the policy given estimated parameters for different values of w_t. Since best responses in the second and third period are similar in the estimated QRE model, there is no difference between the probability of abandoning the

	$w_t = 0$	$w_t = 1$	$w_t = 2$	$w_t = 3$
Majority treatment ($Q = .76,\ p = .35$)	.67	.43	.14	.04
Majority without $t = 2$ ($Q = .77,\ p = .14$)	.87	.64	.17	.04
Optimal treatment ($Q = .87,\ p = .11$)	.93	.71	.11	.01
Pooled data ($Q = .78,\ p = .07$)	.93	.73	.18	.03

Table 5: Probabilities of stopping the policy conditional on w_t high signals

project in the second and third periods. The estimations are relatively close the observed frequencies, except for majority treatment when including $t = 2$.

Finally, we attempt to classify subjects in persistent types, best-responder or overoptimistic, using likelihood ratios. For the majority treatment, every subject participated in 15 repetitions of the game and made at least once decision, so that for every subject we have between 15 and 45 observations. Similarly, for the optimal treatment, we have between 15 and 30 decisions for every subject.

Persistent best responder and overoptimistic types have different likelihood functions, and we compare the odds of them. For all estimated decision making errors the best response is to start a project and to vote further according to the signal player received. Hence, if we denote by k_t^v the amount of times then player voted $v \in \{0, 1\}$ in period t, we can write down the following likelihood ratio:

$$\lambda(Q,k) = \frac{\left(Q + \frac{1-Q}{2}\right)^{k_1^1}\left(\frac{1-Q}{2}\right)^{k_1^0} \prod_{t\in\{2,3\}} \left\{\left(Qs_t^i + \frac{1-Q}{2}\right)^{k_t^1}\left(Q(1-s_t^i) + \frac{1-Q}{2}\right)^{k_t^0}\right\}}{\prod_{t\in\{1,2,3\}} \left\{\left(Q + \frac{1-Q}{2}\right)^{k_t^1}\left(\frac{1-Q}{2}\right)^{k_t^0}\right\}}.$$

The numerator corresponds to the likelihood that the player is a best-responder given Q, while the denominator corresponds to the likelihood that the player is overoptimistic given Q. If $\lambda(Q,k) > 20$ we classify a player as best responder, if $\lambda(Q,k) < \frac{1}{20}$ we classify player as overoptimistic, otherwise the player is unclassified. One can interpret $20 : 1$ odds, for descriptive purposes, as indicating with 95% confidence that the subject is correctly classified by the estimated model.

	Majority	Majority without $t = 2$	Optimal	Pooled
best responders	.50	.97	.79	.62
unclassified	.28	.03	.21	.25
overoptimistic	.22	.00	.00	.13

Table 6: Classification of subjects

Table 6 presents the fraction of subject classified by treatment and with pooled data. For every column we use the parameter Q estimated from the sample (see Table 4). Except for majority treatment when including $t = 2$, subjects are either classified as best-responders or left unclassified, with few exceptions. This is further evidence against persistent overoptimistic types.

Note that the observed over experimentation cannot be explained by risk aversion. The more risk-averse players are, the more they would under experiment. We conclude that the observed behavior may be due to over optimism, but not to persistent types.

5 Final remarks

We construct a simple three-period political economy model of experimentation. In the model, after a policy is adopted, individual voters may obtain or not conclusive signals that they will be winners from the policy. We show that majority rule may have a bias toward under experimentation, capturing a strategic consequence of collective experimentation first identified by Strulovici (2010), and describe an optimal voting rule. The optimal voting rule either requires unanimity for abandoning the policy in intermediate stages, or simply eschews voting in intermediate stages.

We implement the model in the lab with three-player groups. Against equilibrium predictions, we find over experimentation in the lab when there is little evidence in support of adopting the policy under both majority voting and the (theoretically) optimal voting rule. This causes majority voting to outperform the optimal voting rule: allowing voters to vote at intermediate stages about the policy allows them to reduce the probability that the policy is adopted for good by mistakes made in the final stage.

We interpret mistakes in favor of adopting the policy for good in the final stage as a consequence of over optimism. We find very little evidence in support of persistent overoptimism for individual subjects in the lab implementation. Some of the results may reflect the complexity of the strategic calculus for lab participants when best response behavior given the actual behavior of other players conflict with equilibrium predictions. Also, the impact of individual mistakes on group decision may be lower in larger groups. Finding ways to provide subjects with more feedback about the behavior of other subjects without stretching the design beyond what is reasonable, and using larger groups, seem avenues worth exploring.

Appendix A: Proofs

Lemma 1. *The utilitarian social planner and majority voting outcomes coincide in the third period if and only if*

$$\frac{1}{2} < \frac{h-s}{s-r} < 2.$$

Proof. Since by assumption $r = p_2 h + (1 - p_2) l < s$, only players who received high signals would vote to adopt the policy in the last period. Therefore, under the majority rule the outcome would be to implement the policy if there were at least two good signals and abandon otherwise. The utilitarian social planner, instead, would make a decision based on the total welfare amount. The total utility from abandoning the policy in favor of safe alternative is $3s$, the payoff from implementing the risky alternative after two high signals is $2h + r$, and the payoff from implementing the project after receiving only one high signal is $h + 2r$. The condition in the lemma guarantees that the social planer's actions to coincide with majority voting. □

Lemma 2. *If $w_1 = 1$, voters will abandon the policy in the second period if and only if*

$$\frac{h-s}{s-r} < 1 - p_1 q.$$

Proof. Suppose $w_1 = 1$, and consider the players who did not receive a high signal. Their expected payoff can be decomposed in the following three cases:

(i) The player receives a high signal in the next period. Then the player's payoff is h for sure, since there are at least two agents with high signals and the project will be implemented.

(ii) The player does not receive a high signal but the other player does. Then the player's payoff is r since there are two players receiving high signals and the policy will be implemented.

(iii) None of the two players receive high signals in the next period. Then, the player's payoff is s since the project will be abandoned.

The expected payoff from voting for continue experimenting is then:

$$E\pi(\text{Continue}) = p_1 q h + p_1 q (1 - p_1 q) r + (1 - p_1 q)^2 s.$$

The alternative is to abandon the project and receive the safe payoff. Hence, the net gain of adopting the policy is

$$E\pi(\text{Continue}) - s = p_1 q \left((h - s) + (1 - p_1 q)(r - s) \right),$$

which is negative if and only if $(h - s)/(s - r) < 1 - p_1 q$. Hence, under the condition of the lemma, the two players who did not receive the high signal prefer to abandon the policy in the second period. □

Lemma 3. *If $w_1 = 0$, voters will continue the policy in the second period if and only if*

$$\frac{h-s}{s-r} \geq \frac{1-p_1 q}{2-p_1 q}.$$

Proof. Suppose $w_1 = 0$ and consider any of the three players. If the policy continues, it will be adopted in the final period in two cases:

(i) The player obtains a high signal and at least another player does. The probability of this event is $p_1 q(2p_1 q(1-p_1 q) + (p_1 q)^2) = (p_1 q)^2(2-p_1 q)$, and in this case the player obtains a payoff of h.

(ii) The player does not obtain a high signal but the other two players do. The probability of this event is $(1-p_1 q)(p_1 q)^2$, and in this case the player obtains a payoff of r.

In the remainder event the policy is not adopted in the final period and the player obtains a payoff of s. Hence, the net gain of adopting the policy is:

$$E\pi(\text{Continue}) - s = (p_1 q)^2 \left((h-s)(2-p_1 q) + (r-s)(1-p_1 q)\right),$$

which is negative if and only if $(h-s)/(s-r) < (1-p_1 q)/(2-p_1 q)$. Hence, the player prefers to abandon the policy in the second period if and only if this inequality holds. □

Lemma 4. *If*

$$\frac{1-p_1 q}{2-p_1 q} \leq \frac{h-s}{s-r} < 1-p_1 q,$$

voters will start experimenting with the policy in the first period.

Proof. First, let us find the probability of receiving a high payoff for sure in the last period if the reform is started. There are two possible cases: either the player receives a high signal at $t = 1$ (which occurs with probability $p_0 q$) or the player does not receive a high signal at $t = 1$ but receives a high signal at $t = 2$ (which occurs with probability $(1-p_0 q)p_1 q$). The following table summarizes the probabilities of implementing the policy conditional on possible events in these two cases.

High signal received at t	w_1	w_2	Probability
1	2	2 or 3	$2p_0 q(1-p_0 q)$
1	3	3	$(p_0 q)^2$
2	0	2	$(1-p_0 q)^2 2(p_1 q)(1-p_1 q)$
2	0	3	$(1-p_0 q)^2(p_1 q)^2$
2	2	3	$(p_0 q)^2$

In the table we use the fact that the project is stopped if there is only one high signal received in the first period, as implied by Lemma 2.

Now, let us calculate the probability of receiving a payoff of r if the reform is started. In this case player cannot receive a high signal, which happens with probability $(1-p_0q)(1-p_1q)$. Then, the project is implemented if either both other players receive high signals at $t=2$ (which happens with probability $(p_0q)^2$) or neither of them receive a high signal at $t=2$ and both receive high signals at $t=3$ (which happens with probability $(1-p_0q)^2(p_1q)^2$).

Then, the expected net gain of adopting the policy in the first period is:

$$\begin{aligned} E\pi(\text{Continue}) - s &= (h-s)\left[p_0q\left(2p_0q(1-p_0q)+(p_0q)^2\right)\right. \\ &\quad \left. +(1-p_0q)p_1q\left((1-p_0q)^2(2(p_1q)(1-p_1q)+(p_1q)^2)+(p_0q)^2\right)\right] \\ &\quad +(s-r)(1-p_0q)(1-p_1q)\left[(p_0q)^2+(1-p_0q)^2(p_1q)^2\right]. \end{aligned}$$

Substituting and simplifying,

$$\begin{aligned} E\pi(\text{Continue}) - s &= (h-s)(p_0q)^2\left[2-p_0q^2+(1-q)^2(2-3p_0q+p_0q^2)\right] \\ &\quad +(s-r)(p_0q)^2(1-2p_0q+p_0q^2)(1+(1-q)^2). \end{aligned}$$

Thus, every player prefers to adopt the policy in the first period if

$$\frac{h-s}{s-r} \geq \frac{(p_0q)^2(1-2p_0q+p_0q^2)(1+(1-q)^2)}{(p_0q)^2\left[2-p_0q^2+(1-q)^2(2-3p_0q+p_0q^2)\right]}, \tag{1}$$

or equivalently

$$\frac{h-s}{s-r} \geq \frac{(1-p_0q)(1-p_1q)(1+(1-q)^2)}{1+(1-p_0q)[(1-q)^2+(1-p_1q)(1+(1-q)^2)]}.$$

We can rewrite this inequality as

$$1+\frac{1}{1-p_1q}+\frac{p_0q}{(1-p_0q)(1-p_1q)(1+(1-q)^2)} \geq \frac{s-r}{h-s},$$

while we can rewrite the condition for Lemma 3 as

$$1+\frac{1}{1-p_1q} \geq \frac{s-r}{h-s},$$

which is more demanding. □

Lemma 5. *Suppose*

$$\frac{1}{2} \leq \frac{h-s}{s-r} < 1-p_1q.$$

Then, the voting rule that requires simple majority to start the project in the first period and to adopt if for good in the third period, but specifies no voting in the second period, implements the utilitarian social planner outcomes.

Proof. Since the condition of Lemma 1 is satisfied, simple majority outcomes in the last period coincide with the utilitarian outcomes. It remains to be shown that voters adopt the policy under simple majority in the first period when they know that there will be no voting until the final period.

The calculation is similar to the one in the proof of Lemma 4. To the events leading to receiving a high payoff for sure in the last period, we have to add the events in which only one high signal is received in the first period:

High signal received at t	w_1	w_2	Probability
1	1	2	$(1-p_0q)^2 2p_1q(1-p_1q)$
1	1	3	$(1-p_0q)^2(p_1q)^2$
2	1	2 or 3	$2p_0q(1-p_0q)$

Thus, respect to the calculation in the proof of Lemma 4, equation 1, the probability of receiving a payoff of h in rather than s in the third period increases in

$$p_0q(1-p_0q)^2\left(2p_1q(1-p_1q)+(p_1q)^2\right)+(1-p_0q)p_1q2p_0q(1-p_0q),$$

or equivalently,

$$p_0q(1-p_0q)^2\left(2p_1q(1-p_1q)+(p_1q)^2+2p_1q\right)\equiv A.$$

Similarly, to the events leading to receiving a expected payoff of r in the last period, we have to add the event in which only one high signal is received by other players in the first period, with the other player receiving a high signal in the second period, which has probability $2(p_0q)(1-p_0q)p_1q$. Thus, respect to the calculation in the proof of Lemma 4, the probability of receiving a payoff of r in rather than s in the third period increases in

$$(1-p_0q)(1-p_1q)2p_0q(1-p_0q)p_1q,$$

or equivalently,

$$p_0q(1-p_0q)^2(1-p_1q)(2p_1q)\equiv B.$$

Following the steps of the proof of Lemma 4, the condition for players to vote for adopting the policy in the first period is then

$$\frac{h-s}{s-r}\geq\frac{(p_0q)^2(1-2p_0q+p_0q^2)(1+(1-q)^2)+B}{(p_0q)^2\left[2-p_0q^2+(1-q)^2(2-3p_0q+p_0q^2)\right]+A}.$$

It is easy to check that $A > B$, so if inequality 1 is satisfied, the condition above is satisfied as well. $\square$

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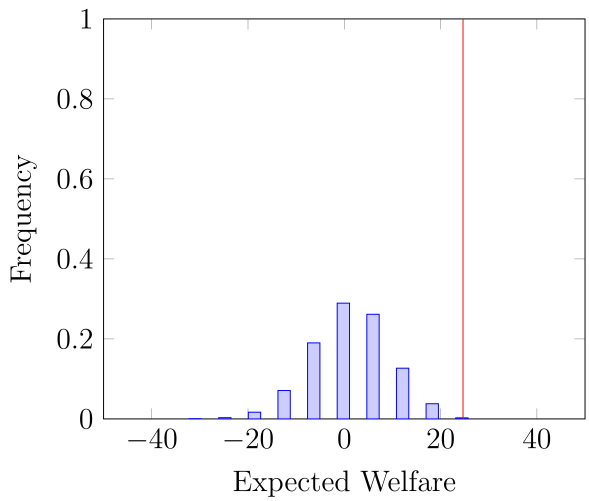
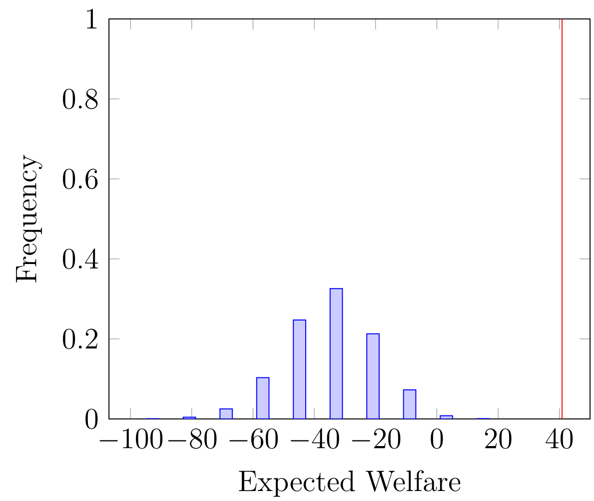
Appendix B (for online publication only): Estimation of expected earnings

We conduct a two-step procedure to estimate expected revenues. The algorithm selects the history according to the theoretical distribution from Table 2. Then, it randomly picks observations from the subsample of observed decisions given the history of the signals chosen. Bootstrapped sample sizes correspond to the observed sample sizes. Further, the algorithm calculates expected revenues (given the theoretical distribution), and allows us to create the distribution of expected earnings for every treatment. We generate a sample of 10000 expected earnings using this technique. The results are based on these estimates.



(a) Majority



(b) Optimal

Figure 9: Expected Earnings

Figure 9 presents expected earnings obtained from the procedure explained above. Red lines show the equilibrium level of earnings, as predicted by the theoretical model. We see that both treatments lie significantly below the equilibrium earning levels. The bootstrapped means are 1.31 (median is 1.49) for majority and -34.73 (median is -35.35) for the optimal treatment. Moreover, the expected earnings from the optimal treatment are significantly below those from the majority treatment ($p < .001$).

Appendix C (for online publication only): Experimental instructions

We provide first the instructions for the majority treatment and next the instructions for the optimal voting rule treatment.

Instructions

Welcome to our experiment! You have earned $5 by showing up on time. If you read and follow the instructions below carefully, you have the potential to earn up to $35. In the experiment you will earn Experimental Dollars (E$s) which will be converted into cash at the end of the experiment. **For every 20 E$ you have at the end of the experiment you will be paid 1 US Dollar.** You will NOT be told the names of those in your group and they will NOT be told your name. All participants have identical instructions. NO communication with other participants is allowed during this experiment. Please switch off your cell phones. If you have any questions please raise your hand, and the experimenter will assist you individually.

Decision Task

There are 15 rounds in this experiment. At the end of this experiment, only 1 round will be randomly selected to determine your final payment. Every round has equal chance of being chosen as the payoff round, therefore **it is in your best interest to treat each round as if it is the one that determines your payment.**

At the beginning of each round, three players will compose a group, and each of you will get a Player ID (for example, Player 1, Player 2 or Player 3). **The Player ID may vary from round to round. For each round, you will be randomly placed in a new group.**

There is one project at each round (different project at different round). You and the other two group members jointly decide whether or not to implement a project. If a project is implemented, each of you has 50% chance to receive a high payoff: **E$500**, and a 50% chance to receive a low payoff: **E$50**. Whether each of you receive a high payoff or low payoff is independently and randomly determined at the beginning of each round. If the project is NOT implemented, each of you will receive **E$350** for sure.

There are **three stages** for each round. At each stage, each of you will choose an action. The **majority action of the group** (i.e. at least two players) will be the action realized.

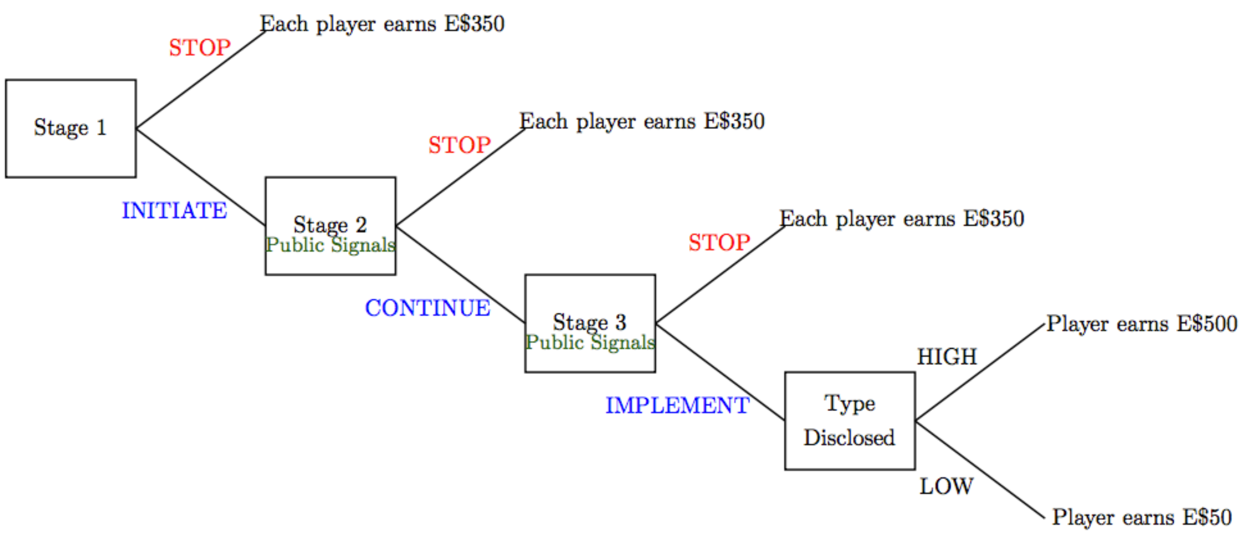
At Stage 1, each of you can choose **INITIATE** or **STOP** the project right away. If the majority of you choose to **STOP**, the project is NOT implemented and this round ends. If the majority of you choose to **INITIATE** the project, each of you will get a signal regarding whether you can receive high payoff if the project is implemented. The signal works in the following way:

The signal is programmed to be either "**High payoff for sure**" or "**Uncertain**." If you are a player who will receive **high payoff** if the project is implemented, **there is 50% chance for you to receive a signal that says "High payoff for sure", and another 50% to receive a signal that says "Uncertain"**. If you are a player who will receive the **low payoff** if the project is implemented, **you will always receive a signal that says "Uncertain."** In other words, if you get a "**High payoff for sure**" signal, you will keep receiving the same signal in the following stage (if any) of the same round, and you know that this round you will receive a high payoff for sure if the project is implemented. If you receive a signal that says "**Uncertain**", it's not clear whether you will receive high or low payoff if the project is implemented. Your signal only reveals your own chance of receiving high or low payoff from this project. Your group members receive different signals regarding their chance. All the signals are public information, that is, they will be observed by all group members.

At Stage 2, you can choose to **CONTINUE** the project or **STOP**. If the majority of you choose to **STOP**, the project is NOT implemented and the round ends. If the majority of you choose to **CONTINUE** the project, each of you will get another signal about whether you are a high payoff player. The signal works exactly the same way as we explained above.

At Stage 3, you can choose to **IMPLEMENT** the project or **STOP**. If the majority of you choose to **STOP**, the project is NOT implemented and this round ends. Otherwise, the project will be implemented. Each group member's payoff will be revealed at the end of the round.

The following graph summarizes the possible decisions and outcomes at each stage. Please raise your hand if you have any questions.



Thank You and Good Luck!

Instructions

Welcome to our experiment! You have earned $5 by showing up on time. If you read and follow the instructions below carefully, you have the potential to earn up to $35. In the experiment you will earn Experimental Dollars (E$s) which will be converted into cash at the end of the experiment. **For every 20 E$ you have at the end of the experiment you will be paid 1 US Dollar.** You will NOT be told the names of those in your group and they will NOT be told your name. All participants have identical instructions. NO communication with other participants is allowed during this experiment. Please switch off your cell phones. If you have any questions please raise your hand, and the experimenter will assist you.

Decision Task

There are 30 rounds in this experiment. At the end of this experiment, only 1 round will be randomly selected to determine your final payment. Every round has equal chance of being chosen as the payoff round, therefore **it is in your best interest to treat each round as if it is the one that determines your payment.**

At the beginning of each round, three players will compose a group, and each of you will get a Player ID (for example, Player 1, Player 2 or Player 3). **The Player ID may vary from round to round. For each round, you will be randomly placed in a new group.**

There is one project at each round (different project at different round). You and the other two group members jointly decide whether or not to implement a project. If a project is implemented, each of you has 50% chance to receive a high payoff: **E$500**, and a 50% chance to receive a low payoff: **E$50**. Whether each of you receive a high payoff or low payoff is independently and randomly determined at the beginning of each round. If the project is NOT implemented, each of you will receive **E$350** for sure.

There are **three stages** for each round. At each stage, each of you will choose an action. The **majority action of the group** (i.e. at least two players) will be the action realized.

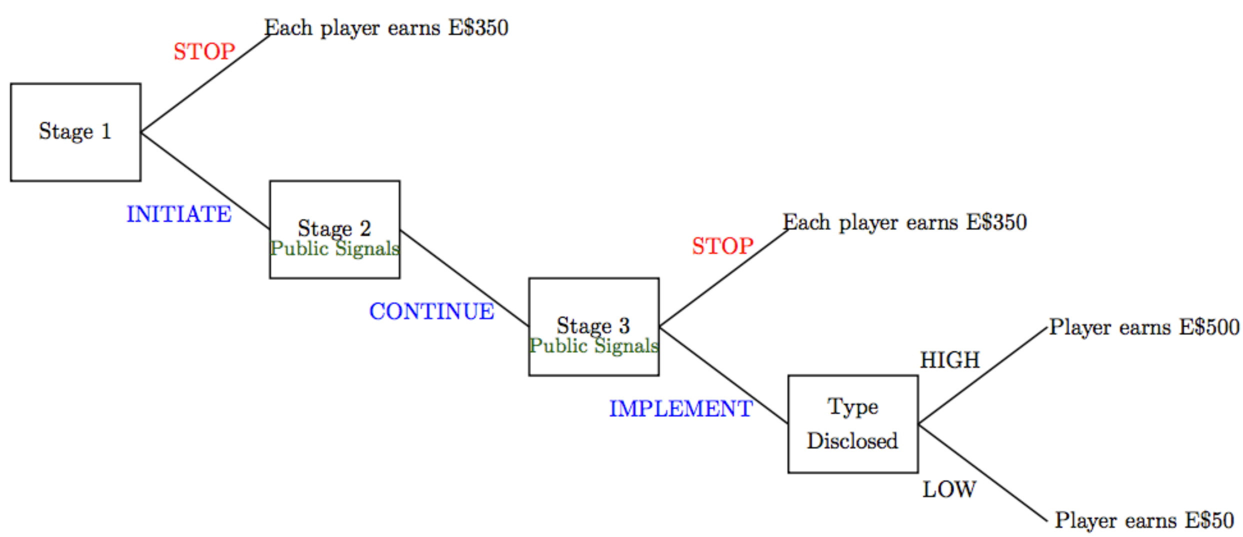
At Stage 1, each of you can choose **INITIATE** or **STOP** the project right away. If the majority of you choose to **STOP**, the project is NOT implemented and this round ends. If the majority of you choose to **INITIATE** the project, each of you will get a signal regarding whether you can receive high payoff if the project is implemented. The signal works in the following way:

The signal is programmed to be either "**High payoff for sure**" or "**Uncertain**." If you are a player who will receive **high payoff** if the project is implemented, **there is 50% chance for you to receive a signal that says "High payoff for sure", and another 50% to receive a signal that says "Uncertain"**. If you are a player who will receive the **low payoff** if the project is implemented, **you will always receive a signal that says "Uncertain."** In other words, if you get a "**High payoff for sure**" signal, you will keep receiving the same signal in the following stage (if any) of the same round, and you know that this round you will receive a high payoff for sure if the project is implemented. If you receive a signal that says "**Uncertain**", it's not clear whether you will receive high or low payoff if the project is implemented. Your signal only reveals your own chance of receiving high or low payoff from this project. Your group members receive different signals regarding their chance. All the signals are public information, that is, they will be observed by all group members.

At Stage 2, the project continues. Each of you will get another signal about whether you are a high payoff player. The signal works exactly the same way as Stage 1.

At Stage 3, you can choose to **IMPLEMENT** the project or **STOP**. If the majority of you choose to **STOP**, the project is NOT implemented and this round ends. Otherwise, the project will be implemented. Each group member's payoff will be revealed at the end of the round.

The following graph summarizes the possible decisions and outcomes at each stage. Please raise your hand if you have any questions.



Thank You and Good Luck!